

# INTEGRATED INVERTER FOR DRIVING MULTIPLE ELECTRIC MACHINES

## STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH

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## TECHNICAL FIELD

The field of the invention is electrical machines including motors and generators and electronic controls for such machines.

## BACKGROUND ART

There are applications that require multiple electric machine drives, such as electric or hybrid electric vehicles, where there is a main traction motor and one or more accessory motors or generators. To control the speed or power of these multiple motors or generators independently, each motor or generator requires an inverter. The use of an inverter enables the motor or generator run in either a motoring mode or a generating mode.

## SUMMARY OF THE INVENTION

The invention relates to an integrated inverter control for controlling multiple electric machines. With the present invention, the number of components in a larger assembly of motors and generators can be reduced when one or more inverters share one or more of the following: a common dc bus, a dc bus filtering capacitor, a gate drive circuit, a processor control circuit, voltage sensors, current sensors, speed sensors or position sensors.

The invention provides advantages of lower cost and a smaller volume for drive systems in specific applications, such as the electric or hybrid vehicle. In this

application, one machine serves as a main traction machine while other machines are used to power accessory devices on the vehicle.

These and other objects and advantages of the invention will be apparent from the description that follows and from the drawings which illustrate embodiments of the invention, and which are incorporated herein by reference.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is an electrical schematic of a three phase inverter of the prior art;

Fig. 2 is an electrical schematic of a four-leg inverter for controlling a two-phase motor/generator;

Fig. 3 is an electrical schematic of a two-leg inverter plus a capacitor leg for controlling a two-phase motor or generator;

Fig. 4 is an electrical schematic of a multiple-motor or generator drive system in which each motor or generator is powered by a separate inverter and all inverters share a single dc source; and

Fig. 5 an electrical schematic of a five-leg integrated inverter of the present invention for driving a three-phase motor or generator and a two-phase motor or generator.

#### DETAILED DESCRIPTION

Fig. 1 illustrates an inverter 10 of the prior art having three parallel legs for phases a, b, and c and six semiconductor switches  $S_1-S_6$ , two switches per leg, for driving a three-phase motor/generator 11. Because the switches  $S_1-S_6$  conduct current only in one direction, each switch has a diode  $D_1-D_6$  connected in parallel, to allow currents to flow in the opposite direction when needed. The inverter is fed by a dc voltage from a dc source 12.

Fig. 2 shows a known inverter 20 with eight semiconductor switches  $S_1-S_8$  in four parallel legs, two switches per leg, for driving a two-phase motor/generator 21. Diodes  $D_1-D_8$  are provided for the same reasons as diodes

$D_1$ - $D_6$  in Fig. 1. A dc voltage bus voltage is provided by a dc source 21 as in Fig. 1.

Fig. 3 shows a known two-leg inverter 30 with four switches  $S_1$ - $S_4$  in two parallel legs with filtering capacitors  $C_1$  and  $C_2$  in a third parallel leg for driving a two-phase motor/generator 31 like the one shown in Fig. 2. Diodes  $D_1$ - $D_4$  are provided for the same reasons as the diodes in Figs. 1 and 2. A dc bus voltage is provided by a dc voltage source 32 as described for Figs. 1 and 2.

Fig. 4 shows a configuration of multiple-machine drives in which each machine #1, #2, through #N (a selected number) is powered by a separated corresponding inverter (#1, #2, through #N) and all the inverters receive dc power from a single dc source 41. Each individual drive unit #1, #2 through #N and inverter #1, #2, . . . #N has an inverter power circuit 42, a dc voltage input sensor 43, a filtering capacitor  $C_1$  connected across the dc bus, and a control circuit 44 connected through gate drivers 45 to the inverter power circuit 42. A current sensor 46 is provided to sense the output current provided to the motor/generator unit #1. The inverter power circuit 42 includes power semiconductor switches  $S_1$ - $S_6$  for three phase voltages as shown in Fig. 1. Inverters #2 through #N can include the configurations for semiconductor switches shown in Figs. 1, 2 or 3.

Fig. 5 illustrates an integrated inverter control 50 of the present invention having a three-phase inverter 50a and a two-phase inverter 50b. The three-phase inverter 50a has three parallel legs for phases a, b and c with six semiconductor switches  $S_1$ - $S_6$  for driving a three-phase motor/generator 57. The two-phase inverter 50b also has two legs,  $\alpha$  and  $\beta$  with four semiconductor switches  $S_7$ - $S_{10}$  for driving a two-phase motor/generator 62.

The inverter receives dc power from a dc source, 51, a filtering capacitor,  $C_1$  is provided across the dc source input. In addition, a gate driver circuit 53 is provided to turn on or off the semiconductor switches,  $S_1$ - $S_{10}$  according to the control signals generated by the processor control circuit 54. A dc source 52 provides the dc bus voltage and

this voltage is sensed through voltage sensor 53 which is electrically connected to processor control circuit 54.

The two-phase motor/generator 62 has two phase windings 64, 65, for phase- $\alpha$  and phase- $\beta$ , and the two phase windings 64, 65 are connected at one end to form a common terminal,  $T_{com}$ , with the other ends remaining separated to form two independent terminals,  $T_\alpha$  and  $T_\beta$ .

The first three legs, a, b and c of the inverter consisting of the switches  $S_1-S_6$  forms a three-phase inverter 50a, which is controlled by pulse width modulation method of a type known in the art to provide three sinusoidal currents to the three-phase motor/generator 57. The three sinusoidal currents have a phase shift of one hundred and twenty (120) electrical degrees relative to each other. The remaining two legs,  $\alpha$  and  $\beta$  are connected to the independent terminals  $T_\alpha$ ,  $T_\beta$  of the two-phase motor/generator 62, respectively. The common terminal,  $T_{com}$  is connected to the neutral point, N of the three-phase motor/generator 57. The two phase legs,  $\alpha$  and  $\beta$ , through pulse width modulation, provide two sinusoidal currents to the two-phase motor/generator 62. The two phase currents have a phase shift of ninety (90) electrical degrees relative to each other. The sum of the two phase currents will split evenly into three parts and each part flows through one of the phase windings of the three-phase motor/generator 57 and the associated phase leg, a, b, c of the three-phase inverter 57 as the return paths. The two-phase motor/generator 62 currents are therefore zero-sequence components to the three-phase motor/generator 57 and will not affect the operation of the three-phase motor generator 57 because the zero-sequence currents will not produce torque. As a result, the torque-producing currents of the two motors/generators 57, 62 can be controlled independently from each other.

A single control circuit, typically based on a microprocessor or digital signal processor (DSP) 54, may be programmed to execute control algorithms for the two motors/generators 57, 62. With a proper control algorithm,

the motors/generators 57, 62 can be run in either motoring mode, i.e., providing power to the motor shaft, or generating mode, in which power is transferred from the motor shaft to the inverter dc source. The motor/generator machines 57, 62 can be ac synchronous machines, ac induction machines or permanent magnet machines. Voltage and current sensors 53, 56 may be used, if necessary, to measure the dc bus voltage and motor/generator currents, respectively. Other sensors such as speed sensors, position sensors or thermocouples may also be employed.

The integrated inverter of the present invention can be extended to drive more than two motors/generators. For each additional two-phase motor/generator, two inverter phase legs would be added to the dc bus 70. The two phase legs drive the two independent motor terminals while the common terminal is connected to the neutral point, N, of the three-phase motor/generator 57. When there are two or more two-phase motors/generators 62, the common terminals of any two of them can be tied together and may or may not be connected to the neutral point, N, of the three-phase motor/generator 57.

Thus, with the present invention, the number of components in a larger assembly of motors and generators can be reduced by sharing a common dc bus, a dc bus filtering capacitor, a gate drive circuit, a processor control circuit, voltage sensors, current sensors, speed sensors or position sensors.

This has been a description of several preferred embodiments of the invention. It will be apparent that various modifications and details can be varied without departing from the scope and spirit of the invention, and these are intended to come within the scope of the following claims.